Chapter 3
Borrow Site Characteristics

3-1. Borrow Source Types

Borrow sources for beach fill can be divided into four general categories: terrestrial, back-barrier, offshore, and navigation channels. Each category has favorable and unfavorable aspects; however, selection of an optimum borrow source depends more on individual site characteristics relative to project requirements than type of source.

a. Terrestrial sources. Terrestrial sources of material suitable for beach fill can be found in many coastal areas. Ancient fluvial and marine terrace and channel deposits, and certain glacial features such as eskers and outwash plains often contain usable material. Because of their potential economic value, information on sand and gravel deposits is often collected by state geological surveys. With this information, field investigations can be focused on a few likely sources, thus eliminating the need for more general exploration. In some places, existing commercial sand and gravel mining operations may provide suitable material for direct purchase. In their absence, it would be necessary to locate a suitable deposit and set up a borrow operation specifically for the project. Use of terrestrial borrow sites usually involves lower costs for mobilization-demobilization operations and plant rental, and less weather downtime than the use of a submerged borrow source. However, the production capacity of terrestrial borrow operations is comparatively low, and haul distances may be relatively long. Thus, costs per unit volume of placed material may exceed those from alternate submerged sites. In general, terrestrial borrow sources are most advantageous for .projects where exploration and mobilization-demobilization costs are a relatively large part of overall expenses for the fill operation.

b. Back-barrier sources. Sediment deposits in the back-barrier marsh, tidal creek, and lagoon environments behind barrier islands and spits have been used for beach fill. They are an attractive source of fill because they are protected from ocean waves and are often close enough to the project beach to allow direct transfer of the material by pipeline. This eliminates the need for separate transport and transfer operations. However, most back-barrier sediments are too fine-grained to use as beach fill. In addition, some back-barrier areas are highly important elements in the coastal ecosystem and are sensitive to disturbance and alteration by dredging (EM 1110-2-1204).

(1) The occurrence of material in back-barrier sediments that is coarse enough for consideration as beach fill is generally confined to overwash deposits and flood tidal shoals associated with active or relict inlets. Overwash deposits occur on the landward margin of the barrier where storm waves have carried beach and dune sediments across the island or spit. Flood tidal shoals occur inshore of tidal inlets and consist of sediment transported by tidal currents flowing in and out of the inlet. These sediments are usually transported into the inlet-influenced area by tidal current processes and can be derived from littoral drift from adjacent beaches.

(2) Overwash deposits and relict flood tidal shoals may be ecologically important because they may provide suitable substrate for marsh growth. In addition, on retreating barriers, they comprise a reserve of sand that will be recycled into the active beach deposits as retreat progresses. Flood tidal shoals associated with an active inlet are more suitable for borrow sites because the material removed is likely to be replaced by ongoing inlet processes. However, dredging material from active flood tidal shoals can adversely alter the hydraulic conditions in the inlet area. A study of the hydraulic effects should be made prior to altering the flood tidal shoals by dredging. For further detailed information on the hydraulic effects of dredging see EM 1110-2-1618.

c. Navigation channels. Creation of navigation channels and deepening or maintenance dredging of existing channels often involve the excavation and disposal of large volumes of sediment. In some cases where the dredged sediment is of suitable quality, it can be used as fill on nearby beaches rather than placing it in offshore, upland, or contained disposal sites. Operations of this type are economically attractive because dual benefits are realized at considerably less cost than possible if both operations were carried out separately. Details concerning the use of dredged material for beach fill are discussed in EM 1110-2-1616.

(1) Maintenance dredging of channel fill in low-energy environments such as estuaries or protected bays is least likely to produce suitable fill material. In such areas, channel fill often consists of material in the clay, silt, and very fine sand size range. However, in dredging of new channels or deepening of existing channels in low-energy areas, the dredge may cut into relict material of suitable characteristics.

(2) Channel fill from higher energy areas such as rivers above tidewater and open coast inlet shoals is often more acceptable for beach fill. On barrier coasts, inlet fill usually consists of beach material that has been carried to the inlet by littoral drift. It needs to be determined if the borrow

material is closely similar to the native material on the project beach.

d. Offshore sources. Investigations of potential offshore sources of beach fill material under the CERC Inner Continental Shelf Sediments Study, by Corps Districts and others such as Bodge and Rosen (1988), indicate that large deposits of suitable material often occur in offshore deposits. The data, largely from the Atlantic coast at present, show that the most common occurrences are in ebb tidal shoals off inlets, and in linear and cape-associated shoals on the inner continental shelf. Potential sources on the inner shelf have also been identified in submerged glaciofluvial features, relict-filled stream channels, and featureless sheet-type deposits.

(1) Offshore shoals on the inner continental shelf such as those shown in Figure 3-1 can serve as potential fill sources. Such deposits can be excavated by dredges designed to operate in open sea conditions. The material can be transported by the dredge itself if it is of the hopper type or by barge, to a more protected site near the project area. It is then dumped in a rehandle pit or offloaded, and transferred to the beach by hydraulic pipeline or truck haul.

(2) An alternate method is to dump material in a nearshore berm as close as possible off the project beach where it will possibly be moved ashore by wave action. Several Atlantic and Gulf projects involve nearshore dumping in 5- to 9-m (16- to 30-ft) water depths. Experiments in offshore dumping near New River Inlet, North Carolina, in a depth of 2 to 4 m (6 to 12 ft) resulted in a general onshore and lateral migration of fill material (Schwartz and Musialowski 1980). Placing material in depths this shallow requires special equipment such as split hull barges, dredges, or other equipment to cast the material shoreward.

(3) Offshore borrow sources have several favorable features. Suitable deposits can often be located close to the project area. Offshore deposits, particularly linear and cape-associated shoals, usually contain large volumes of sediment with relatively uniform characteristics and little or no silt or clay size material. Large dredges with high production rates can be used. Environmental effects can be kept at acceptable levels with proper planning.

(4) Unfavorable aspects of offshore borrow operations are chiefly related to the necessity of operating under open sea conditions, and the alteration of seafloor bathymetry by removing material. Dredges capable of working in open sea conditions generally have relatively large plant rental and operating costs, although this may be offset by greater production capacity. Alterations in bathymetry, especially on shallow shoals such as ebb tidal deltas, may have an unfavorable effect on adjacent shore areas due to alteration of wave characteristics. This should be evaluated prior to selecting such a borrow source by the use of nearshore wave transformation models as described in Chapter 2 of this report.

3-2. Exploration and Identification of Borrow Sources

A field exploration program to locate and characterize potential borrow sources is usually necessary for offshore and back-barrier environments. For a detailed discussion of procedures, see Prins (1980) and Meisburger (1990). In terrestrial areas, there may be existing commercial sand and gravel mining operations. Information on deposits is usually available from state geological surveys. Where navigation projects are underway, information on the characteristics of channel fill or new material is usually available.

a. Field exploration. Field exploration programs involve four phases: preliminary office study, general field exploration, detailed site survey, and evaluation. The area covered by these investigations (survey area) is delimited by the distance from the project site that is within an economically feasible range for transportation of fill material. Generally borrow sources within a few miles of the site should be considered initially. Further distances to sources should be considered only if no suitable sources are available within this range (see EM 1110-2-1802 and EM 1110-2-1804).

(1) The typical first phase of the exploration program consists of a study of existing information on the geology of the survey area. In the second or general exploration phase, a field data collection effort is conducted throughout the survey area to locate and partly characterize potential borrow sources. The third phase involves detailed field data collection on potential borrow sites located during the general exploration phase, and the fourth phase is the evaluation of sediment quality and its effects on the shore.

(2) The principal types of data collection in the field phases are fathometer and seismic reflection surveys, followed by sediment cores in areas of potential sand deposits. Grab samples of surficial sediment and side-scan sonar records are also useful for the general exploration phase, and can usually be obtained for a relatively small additional cost.

(3) The quality of seismic reflection records begins to deteriorate when significant wave height exceeds about 0.6 m (2 ft). Coring operations are also adversely affected by waves and, depending on the vessel being used, cannot

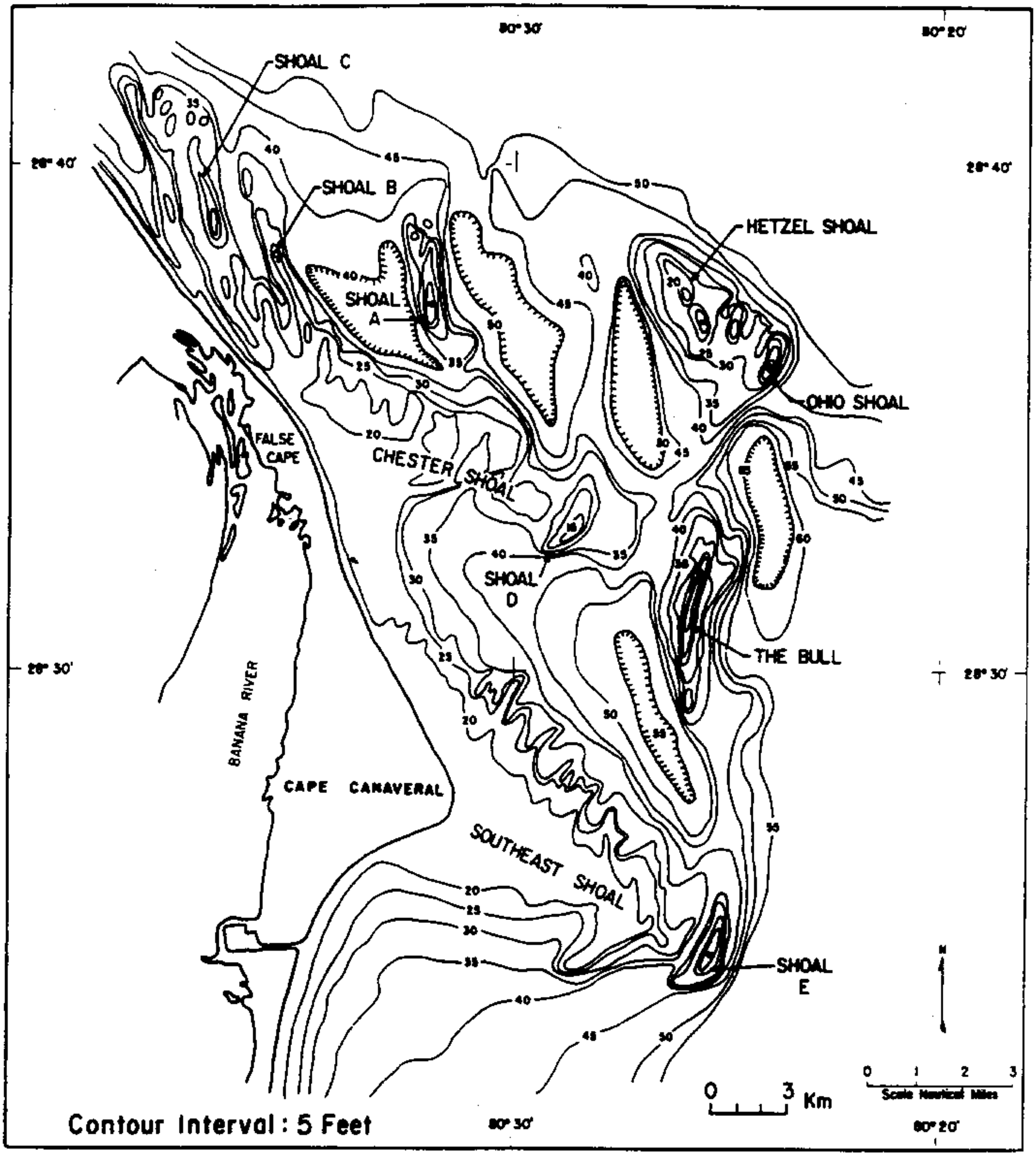

Figure 3-1. Cape-associated inner continental shelf shoals off Cape Canaveral, Florida (Field and Duane 1974)

be safely conducted when significant wave heights exceed 0.6 to 1.2 m (2 to 4 ft). In order to reduce downtime for weather, it is best to carry out the fieldwork during the summer when wave climate is most favorable. The general exploration and detailed site survey phases can either be conducted during a single summer, or over two succeeding summers to allow more time for analysis of the general exploration data and selection of promising sites. However, it is economically preferable to complete all work during a single season and avoid the additional mobilization and demobilization costs.

b. Equipment requirements. Table 3-1, from Prins (1980), contains a list of equipment used for the general field exploration and detailed site survey phases. The most important items are the seismic reflection equipment, vibracore apparatus, the navigation positioning system, and vessels.

(1) Seismic reflection equipment should provide the highest resolution possible consistent with achieving a sub-bottom penetration of 20 m (50 ft) or more. An example of a seismic record taken at a borrow site off Ocean City, MD, can be seen in Figure 3-2. High-powered seismic reflection systems used for many deep penetration studies are not suitable because of their relatively poor resolution of closely spaced reflectors.

(2) Obtaining sediment cores using vibratory coring equipment is more economical than standard soil boring methods which require more expensive support equipment, and have a comparatively low production rate, especially when used in open sea conditions. Vibratory coring equipment having 3-, 6-, and 12-m (10-, 20- and 40-ft) penetration capability are available. For general exploration and detailed site studies, a 6-m coring device is necessary. A 12-m (40-ft) capability is desirable if possible.

(3) Navigation control should be by an electronic navigation system having an accuracy of about 3 m (10 ft) at the maximum range anticipated for survey and coring operations. Global Positioning Satellites technology provides this type of accurate positioning.

(4) For seismic reflection surveys, a vessel capable of operating in open sea locations is needed. The vessel must have a covered cabin space large enough to accommodate the seismic reflection recorders and positioning equipment. Sediment coring operations usually involve a barge equipped with a crane large enough to handle the coring device and have a lifting capacity of about 15 tons in order to accommodate the maximum pullout resistance of the core barrel after penetration.

c. Office study. The first phase of the exploration program is an office study of maps, charts, aerial photographs, and literature sources concerning the survey area. A study of these materials provides general information on the geomorphology and geology of the area, and helps to identify features that may contain potential fill material.

(1) One of the main objectives of this study is to lay out trackline plots similar to those shown in Figure 3-3, to be followed by the survey vessel in collecting seismic reflection data during the general reconnaissance field exploration phase. A grid pattern, as illustrated in Figure 3-4, approximately 0.8 km (0.5 mile) apart should be employed for areas that are judged to be the most important either because they are located near the project site, or give promise of containing deposits of usable fill material (Meisburger 1990). Zigzag lines are used to cover areas between grids. The detail of coverage is determined by trackline spacing; the more complex or promising areas may call for closer spacing.

(2) A tentative pre-selection of core sites can also be made during the office study. However, the final location should be determined by analysis of the seismic reflection records when they become available.

d. General field exploration. During the general field exploration program, data are collected throughout the survey area to locate and obtain information on potential borrow sources and shallow sub-bottom stratigraphy. This phase involves collection of comprehensive coverage of the survey area by seismic reflection profiles and cores to identify and test potential borrow sources. It is also used to identify sediment bodies associated with prominent seismic reflectors.

(1) The initial part of the general exploration phase is the collection of fathometer and seismic reflection records along predetermined tracklines plotted during the office study. The records should be continuously monitored as they become available. Changes in trackline patterns, if considered desirable, should be made as work progresses.

(2) The basic survey procedure is for the survey vessel to proceed along each trackline collecting data while its position is being continuously monitored by an electronic positioning system with fixes recorded at a minimum of 2-min intervals. Fixes are keyed to the records by means of an event marker and identified by a serial fix number. Because seismic reflection records tend to deteriorate in quality with increasing boat speed, the survey vessel should be operated slow enough to avoid significant reduction in

Table 3-1
Equipment Used for General Field Exploration

Seismic Operations

(1) Research vessel:
11.6-m (38-ft) minimum length
3.7-m^2 (40-sq-ft) minimum table space
40-sq-ft minimum deck space
110-volt a.c. power
Compass (gyrocompass desirable)
Marine radio
Cruising range: 160.9-km (100-mile) minimum
Cruising speed: 10-knot minimum

(2) Sub-bottom profiling system:
(a) Medium resolution, medium penetration
Penetration capability: 15.2 to 61.0 m (50 to 200 ft)
Power output: 300 to 1,000 J
Frequency range: 400 Hz to 14 KHz

(b) High resolution, low penetration
Penetration capability: 9.1 m (30 ft)
Power output: 10 Kw
Frequency range: 3.5 to 7 KHz

(3) Side-scan sonar system:
Frequency range: 95 to 100 KHz
Port and starboard scanning capability
142.4-m (500-ft) range in either direction

(4) Geographic positioning system:
Range: 32.2-km (20-mile) minimum
Accuracy: 10 ft

(5) Microprocessor:
Interfacing capabilities with positioning system

(6) Radios:
(a) Marine-band radio
(b) Two-way radio

(7) Vehicles:
Three minimum for shore personnel

Coring Operations

(1) Coring platform:
(a) Tug and barge
Tug: capable of 14.6-km (8-knot) minimum with barge in tow
Barge: Sufficient deck space to accommodate coring device, crane, compressor, and core storage; or
(b) Ship: Requirements same as barge

(2) Reconnaissance boat:
9.8-m (32-ft) minimum length
0.9-m^2 (10-sq-ft) minimum table space
110-volt a.c. power
Compass
Cruising range: 100-mile minimum
Cruising speed: 10-knot minimum

(3) Geographic positioning system:
Range: 32.2-km (20-mile) minimum
Accuracy: 10 ft

(4) Coring device, vibrating:
Capable of 20- to 40-ft cores

(5) Compressor:
8.4 kg/m^2 (120 psi) at 7.1 m^3 (250 ft^3) per minute

(6) Crane:
10-metric-ton (11-short-ton) minimum
30-ft minimum boom length

(7) Bottom grab sampler:
Various types available

(8) Miscellaneous:
Floats, cord, and anchor weights
Logbooks and office supplies
Batteries
Sample bags and waterproof markers
Tools, cables, clamps, and other hardware

record quality. In general, a suitable boat speed is likely to be less than 2 or 3 m/s (4 or 5 knots).

(3) Sediment core sites are usually selected after the seismic reflection survey to allow time for preliminary analysis of the records to determine the most effective core locations. Cores should be examined as they are taken and changes made in the coring locations if it is desirable. Core inspection is often hampered by silt and scratching of the acrylic core liners. However, the top and bottom sediments can be directly viewed before the core is capped.

(4) The coring platform, usually a barge, should be equipped with spud legs or suitable anchors for mooring the platform securely. With vibratory coring equipment that is bottom-mounted and connected with the platform only by a retrieving cable and air hoses, small excursions in position are acceptable.

e. Detailed site survey. The third phase of borrow site exploration and investigation consists of a detailed study of potential sites selected on the basis of data collected during the general exploration survey. In most prior studies conducted by CERC the general and detailed surveys were made in succeeding years so that ample time was available to study results of the seismic reflection survey before coring was undertaken. However, it is possible to complete the operation entirely in one season. This can be done by mobilizing both geophysical and coring equipment early in the most favorable season and using a sufficient lag time

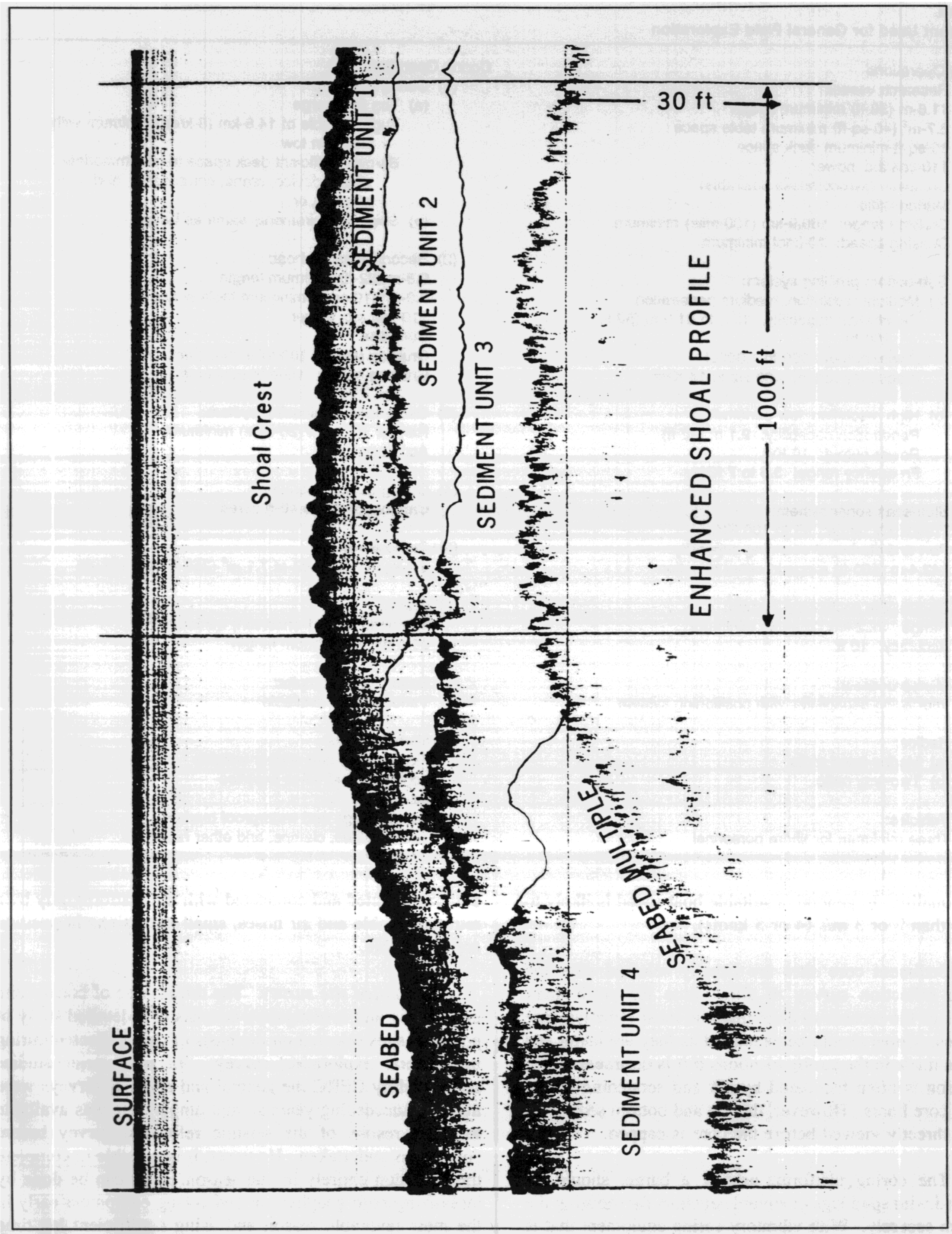

Figure 3-2. Seismic profile record from a potential borrow site near Ocean City, MD (from Anders and Hansen (1990))

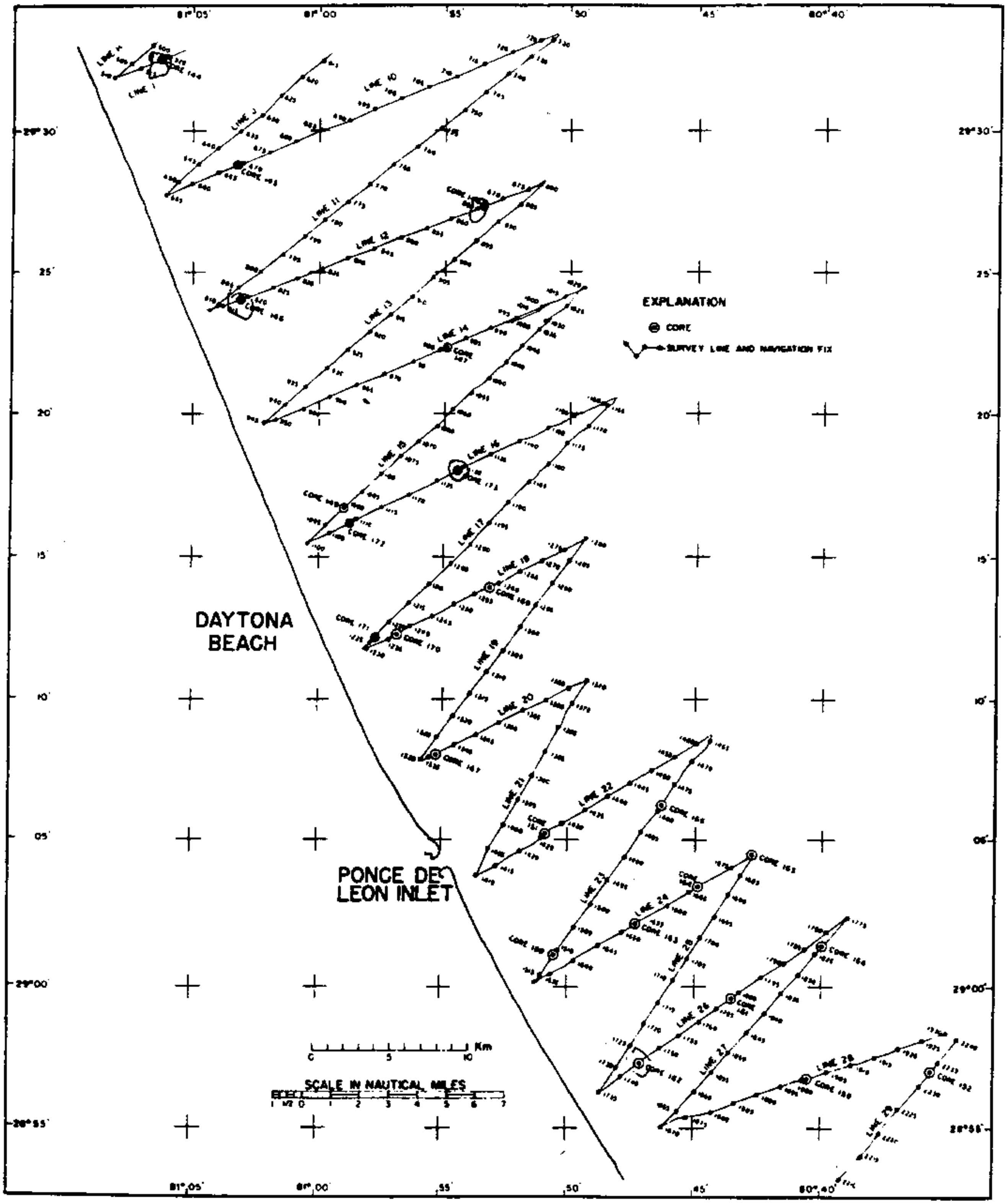

Figure 3-3. Reconnaissance zigzag line plot from the north Florida coast (from Meisburger and Field (1975))

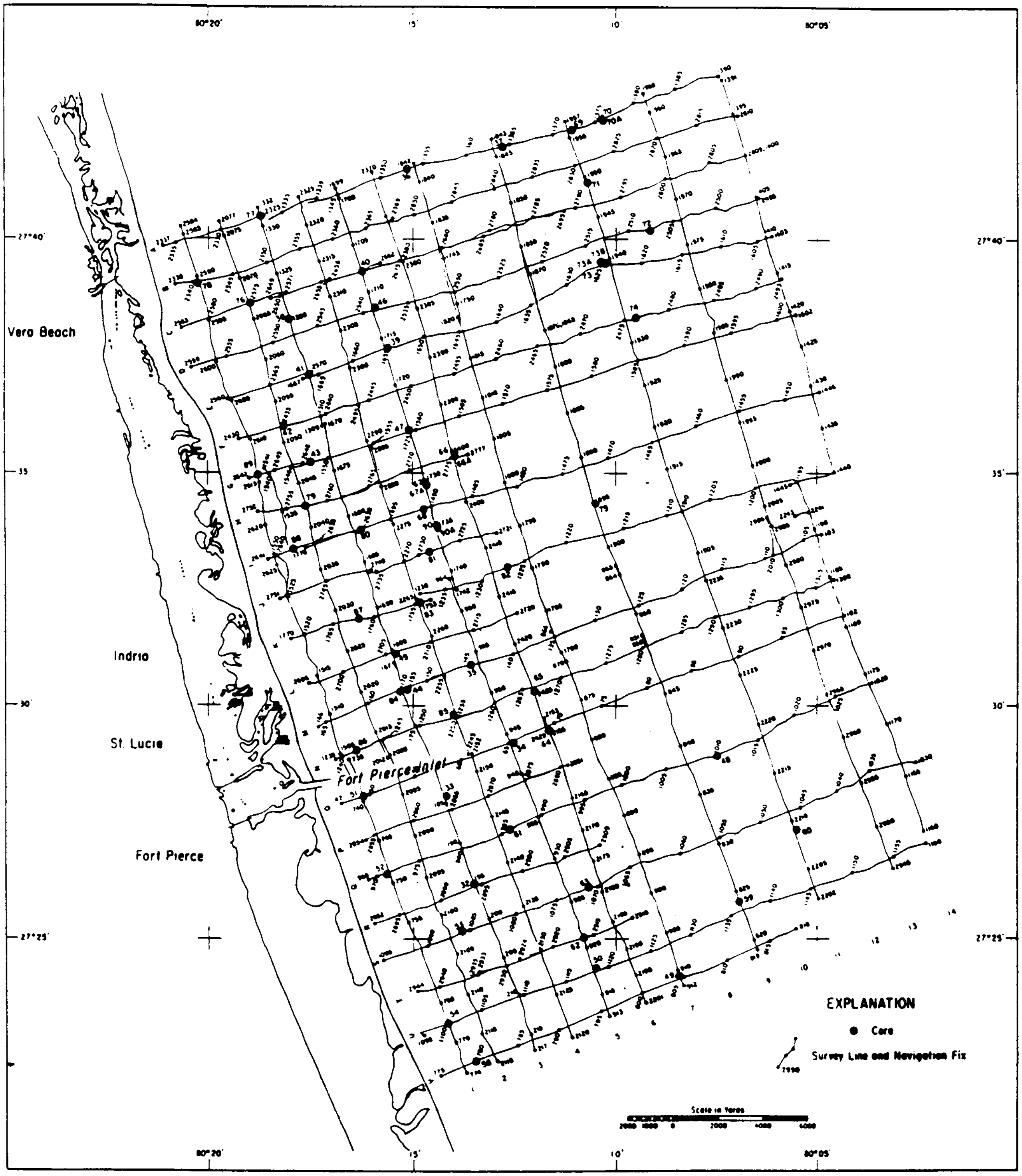

Figure 3-4. Grid lines covering a detailed survey area off Fort Pierce, Florida (from Meisburger and Duane (1971))

between the seismic and coring work so that time is available for record analyses and core site selection to be made. For this purpose one member of the field crew will devote full time to analysis of records on a day-to-day basis to pick core sites for the ongoing coring phase.

(1) If sufficient seismic reflection data were collected on potential sites during the general exploration phase, the detailed site study may involve only collection of additional core data. However, it is important to have adequate data for reliably defining the borrow site. Additional seismic reflection data, if needed, should be collected at this time.

(2) A sufficient number of cores of potential borrow sites should be obtained to thoroughly define the stratigraphy and sediment characteristics. Since core sites will be relatively close in the selected areas, a larger number of cores can be obtained at less cost in the general exploration phase. The bulk of the available time is spent moving between coring stations rather than on the coring process itself. The number of cores and spacing between cores should be determined by a review of survey and seismic data as well as other geological studies of the area. These values will vary across and between borrow sites.

3-3. Site Characterization Requirements

Any beach erosion or shore protection study in which beach fill is considered should contain information on potential borrow sources and a comparative evaluation of their suitability. The characteristics of potential borrow sources that are most important in evaluating suitability are location, accessibility, volume of material available, site morphology, stratigraphy, sediment characteristics, geological history, environmental factors, and economic factors.

a. Location. The location of a borrow site with respect to the project area is an important consideration in evaluating suitability. The distance that material must be moved and feasible means of transport have a large influence on project costs and may be decisive in selecting the most suitable source. Location is also important in terms of the surroundings. Terrestrial sources located in built-up areas may have a direct impact on the population by creating undesirable noise and traffic congestion. Offshore sources may involve questions of jurisdiction and be situated in areas where dredging and transport activities impede or endanger navigation.

b. Accessibility. In order to be usable, a borrow source must be accessible to or made accessible for the equipment needed to excavate and transport the material. Access to terrestrial deposits may involve road construction or improvement of existing routes. Onsite reconnaissance is the best method of finding out the adequacy of access and any necessary improvements. A cost estimate of needed work should be prepared and included in the economic analysis.

(1) In evaluating subaqueous deposits, one of the principal factors is water depth. To be accessible, the deposit must lie in the depth range between the maximum depth to which the dredge can excavate material, and the minimum depth to keep the dredge afloat.

(2) Another aspect of accessibility is presence of overburden above the usable material. The composition, areal extent, and thickness of any overburden should be determined and considered in the economic analysis.

c. Volume available. Most beach fill projects require large volumes of suitable fill material. The volume of material in each potential source must be calculated to determine if a sufficient amount is available to construct and maintain the project for its entire economic life of 50 years. In order to do this, it is necessary to delineate the lateral extent and thickness of the deposit. Boundaries may be defined by physical criteria or, in large deposits, arbitrarily set to encompass ample material for the projected fill operation. Thickness of the usable material can be determined by core or boring data supplemented in subaqueous environments by seismic reflection profiles.

(1) If deposits have a relatively uniform thickness throughout, the available volume can be calculated by multiplying their area times the thickness. Many deposits such as shoals and filled stream channels have sloping boundaries and variable thickness values. To determine the volume of these deposits, an isopach map of the deposit is made and measurements from the map are used to calculate the volume. An isopach map is a contour map showing the thickness of a deposit between two physical or arbitrary boundaries. Figure 3-5 shows an isopach map of a borrow area used at Ocean City, Maryland. In this case, the upper boundary of the deposit is defined by the surface of the shoal and can be delineated by bathymetric data. The lower boundary was fixed at a level horizontal seismic reflection horizon passing beneath the shoal. Contours at 1.5-m (5-ft) intervals were drawn for all the shoal area above the base reflector.

(2) To compute the volume of material within a similar deposit with sloping boundaries, a mid-level contour between each pair of contours, i.e. at half the contour interval, is first delineated. The area enclosed by each of the primary and mid-level contours is measured with a

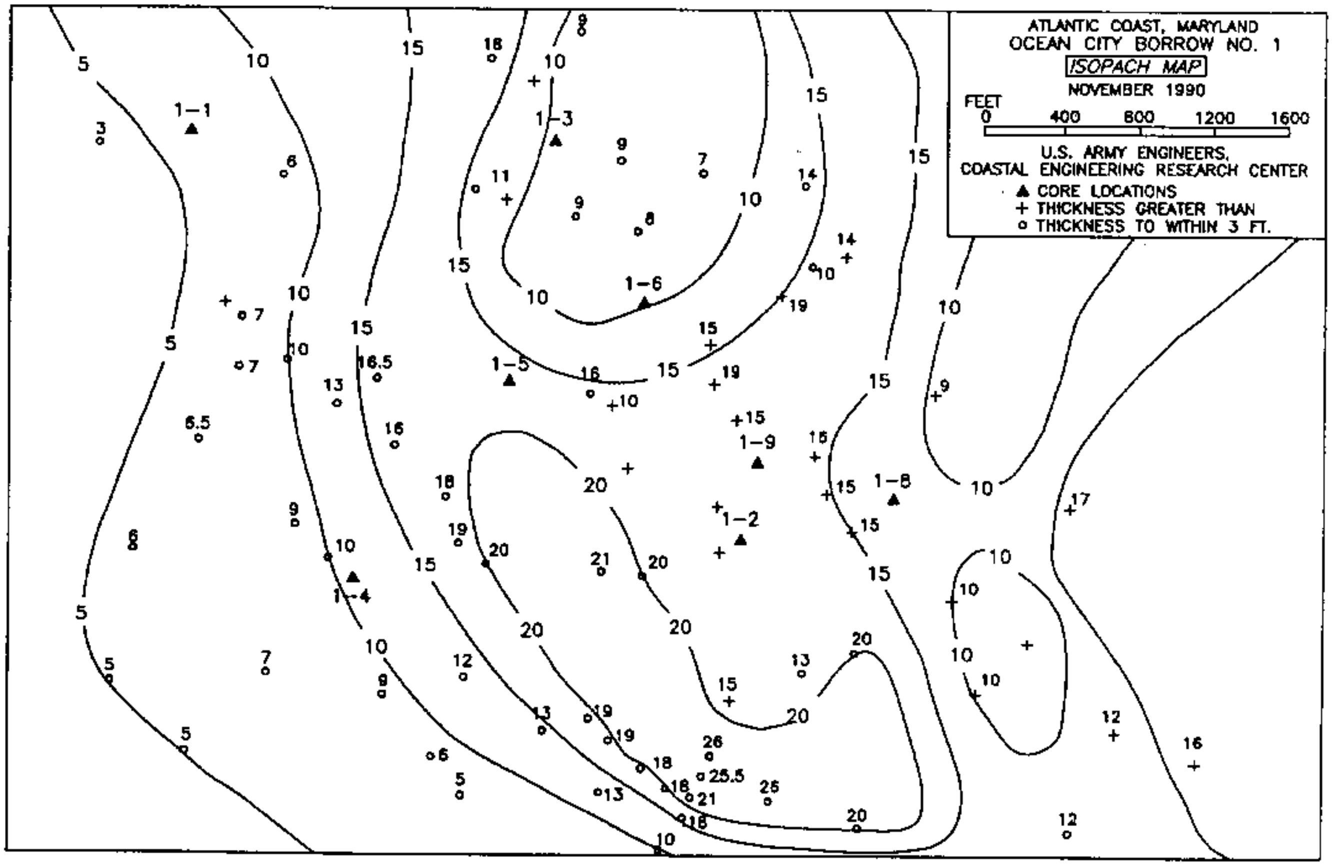

Figure 3-5. Isopach map of sand thickness in shoal of potential borrow site (from Anders and Hansen (1990))

planimeter. The volume of material in each layer between primary contours is then calculated using the prismoidal formula:

$$V = 1/6\ H\ (S_o + 4S_1 + S_2) \qquad (3\text{-}1)$$

where

V = volume
H = primary contour interval
S_0 and S_2 = area enclosed by upper and lower primary contours
S_1 = area enclosed by mid-level contour

Total volume is determined by adding the values of each layer.

d. Site morphology. Information on borrow site morphology is valuable in defining and evaluating site characteristics. In many cases, the source deposit creates surface morphological features that can be used to delineate boundaries and to assist in interpolating between seismic and coring data points. In addition, site morphology may provide indications of the origin and history of the deposit. Subsurface deposits such as filled stream channels are more difficult to delineate because the only sources of data are seismic reflection records, cores, and borings.

(1) Description of borrow site morphology should contain information on dimensions, relief, configuration, and boundaries, and be illustrated by large-scale maps or charts. Information for compiling the reports can usually be found in large-scale hydrographic smooth sheets available from NOAA for submerged deposits, and in published USGS topographic maps for terrestrial sources. Fathometer records, which should be made concurrently with the seismic reflection profiles, are valuable for supplementing and updating other sources.

(2) In some cases, existing information may be inadequate because of the relatively low density of data points for the site area or because the original surveys are outdated. In this event, a special detailed fathometer survey of the site should be made before the main field collection effort is undertaken.

e. Site stratigraphy. Stratigraphic relationships within and peripheral to the site deposits should be developed from the existing sources and the seismic and coring records to define the following:

(1) Limits of the deposit.

(2) Thickness of usable material.

(3) Thickness of any overburden.

(4) Sedimentary structures.

(5) Sediment characteristics of each definable bed.

The detail and reliability of the stratigraphic analysis depend on the complexity of the deposit, the number of outcrops, cores or borings available, and the degree to which stratigraphic features are revealed by seismic reflection profiles.

(1) In terrestrial areas, outcrops of potentially useful materials may or may not be present. In many cases, such deposits have no topographic expression and must be defined solely on the basis of borings. Seismic refraction surveys in such situations are valuable in defining the areas between data points. Seismic refraction techniques for subsurface exploration are covered in detail in EM 1110-1-1802.

(2) In submerged areas, site characteristics must be determined by a combination of bathymetric survey, seismic reflection profiling, and sediment coring. Seismic reflection profiles have some advantages over refraction surveys, but can only be used in water-covered areas. Reflectors appearing on seismic reflection profiles record boundaries between sediment layers having different acoustic properties. Although these boundaries are usually stratigraphically significant, this is not always the case. On the other hand, significant boundaries may not have enough acoustic contrast to produce a definite reflection, or reflectors of importance may be undetected because of insufficient penetration of the acoustic pulses into the sub-bottom sediments. It is important, therefore, in both reflection and refraction surveys, to collect enough cores or boring samples to identify and correlate the reflectors with reliable data on sediment properties, and to show significant boundaries that may not have been recorded by the seismic systems.

f. Sediment composition. The physical properties of a sediment sample that are most important for determination of suitability for fill on a project beach are composition and grain size distribution. The desirable physical properties are mechanical strength, resistance to abrasion, and chemical stability.

(1) In most places, sand size sediment is predominantly composed of quartz particles with lesser amounts of other minerals such as feldspar. Quartz has properties of good mechanical strength, resistance to abrasion, and chemical stability. In some deposits, particularly those of marine origin, there is a large and sometimes dominant amount of calcium carbonate that is in most cases of organic origin (biogenic). Calcium carbonate is more susceptible than quartz to breakage, abrasion, and chemical dissolution. But, if it is not highly porous or hollow, it will make serviceable beach fill.

(2) Sediment composition can be determined by examination of representative samples under a binocular microscope. Samples should be prepared by thorough washing to remove fines and clean the surface of the particles. If the material is not well-sorted, it should be subdivided into sieve fractions for analysis. A subdivision into the Wentworth classes (Table 2-1) for sand size and coarser material is convenient for this purpose.

g. Sediment size characteristics. The size frequency distribution of potential borrow material must be obtained in order to evaluate its suitability for fill on the project beach. Generally, suitable material will have grain sizes predominantly in the fine to very coarse size range. The presence of very fine sand, silt, and clay in small amounts is acceptable, but sources having a substantial amount of fines should be avoided because of the large amount of material that must be handled to obtain the usable portion. Also, the creation of turbidity incident to excavation and placement on the beach is environmentally undesirable.

(1) Since few large sand bodies have uniform size characteristics throughout, it is important to obtain a sufficient number of cores and borings to accurately reflect the variations in size characteristics. This is often difficult because of a lack of direct information on the interior of the deposit. In most cases, all that will be available is seismic reflection data and cores or borings obtained during the initial exploratory survey. Because of this, it is valuable to have a flexible program of core or boring site selection during a detailed site study so that their number and position can be modified on the basis of onsite inspection of the cores or borings as they are obtained.

(2) In certain environments of the inner continental shelf or estuarine and back-barrier areas that are characterized by low wave and current energy, deposits of fine-grained, easily transportable sediment particles may accumulate.

Many of the particles in these deposits have relatively large sieve diameters, but are highly porous, hollow, or have a flattened shape. Characteristic particles or low-energy deposits are mica, minute shells, and fragments of small or immature mollusks, bone fragments, vegetation, and the skeletal parts of various types of bryozoa, foraminifera, ostracods, calcareous algae, and echinoids. In general, material from low energy deposits, regardless of sieve size, is unsuitable for beach fill.

h. Composite sediment statistics. One of the main considerations in selecting a borrow source is the comparative relationship between the grain size distributions of the native beach and the borrow material. For making this comparison, it is necessary to determine, for both native beach and potential borrow source, a composite grain size distribution that is representative of overall textural properties. Methods for composite grain size analysis are discussed in Section 2-4.

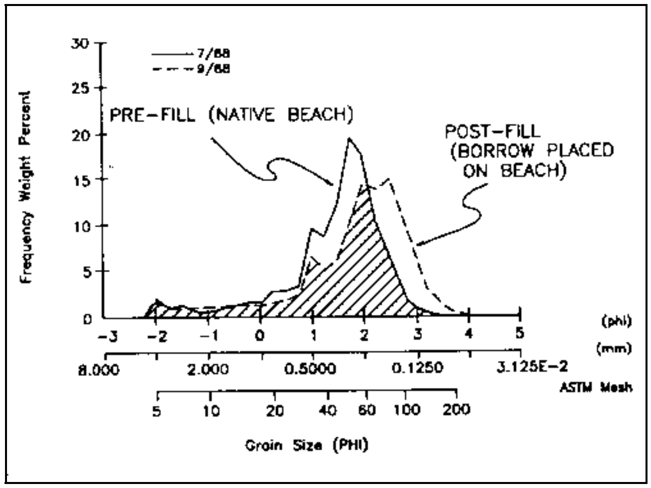

Figure 3-6. Comparison of composite grain size analysis between the native beach and the borrow material used at Ocean City, MD

(1) Native beach composite sediment statistics should consist of a cross-shore composite representing the entire active profile. Sediment samples should be collected from the intertidal and nearshore zones across the profile from mean high water to the nearshore bar as described in Section 2-4. Composite grain size statistics calculated from such a sampling scheme will account for most of the active variability on the profile. If cross-shore composites exhibit a wide range of mean and sorting values, an alongshore composite should be calculated to reduce the variability.

(2) Borrow area composite statistics should be determined using core sediment data from the fill area. Several cores should be taken within the potential borrow site to characterize the extent of useable material. Core samples should be collected from the top, middle, and bottom of useable sand within the core. Composites from both the native beach and borrow area can be compared to aid in the determination of fill suitability. The same method of determining grain size characteristics should be used for both the fill and borrow sites. Figure 3-6 shows a comparison between the native beach and coarse-grained borrow material used for nourishment at Ocean City, MD. The shaded area represents common characteristics between the native beach and fill material.

i. Sand suitability analysis. Fill material, in reality, does not exactly match the native beach material in a project area. Krumbein (1957), Krumbein and James (1965), James (1974), Dean (1974b), and James (1975) have developed similar approaches for indicating the behavior of fill material having different characteristics than that of the native material. These approaches develop a ratio indicating how much fill material is required as a result of the different sediment characteristics between the fill and native materials. Their approaches make the following assumptions: (1) that the native sediment is considered most stable for the environment in which it occurs, (2) sorting of borrow material by coastal processes will achieve a similar grain size distribution as the native beach, given enough time, (3) sorting of borrow material will winnow out a minimum amount of original fill, and (4) that both native and borrow material exhibit normal grain size distributions. These assumptions should be considered with caution. Each grain size class responds to wave transport at different energy levels. The finer grain sizes will likely be winnowed out first, leaving the more stable coarser material. Often, the coarser material is comprised of carbonate shell fragments that break up with time, altering the original grain size distribution. Based on the above assumptions two approaches were developed to determine borrow material suitability for use as beach fill material. These approaches estimate the amount of borrow material needed to produce a certain amount of stable, native-like material (overfill ratio) and how often renourishment will be required (renourishment factor), and are discussed in detail in the *Shore Protection Manual* (1984).

(1) Overfill ratio. Using the assumptions discussed above, James (1975) developed a method for estimating required fill volumes considering the differences between the borrow and native materials. The overfill ratio (R_A) is the volume of borrow material required to produce a stable unit of usable fill material with the same grain size characteristics as the native material. R_A is determined by comparing phi (ϕ) mean sediment diameter and sorting values of the native beach and borrow sediments. The ϕ scale of sediment diameter is defined as:

$$\phi = -\log_2 (D) = -\frac{\ln (D)}{\ln 2} \qquad (3\text{-}2)$$

where D is the sediment grain size diameter in millimeters. For example, sand that has a 0.2-mm diameter has a ϕ value of 2.3.

(a) The adjusted overfill ratio (R_A) is determined using the following relationships between the borrow and native beach material:

$$\frac{\sigma_{\phi b}}{\sigma_{\phi n}} \qquad (3\text{-}3)$$

and

$$\frac{M_{\phi b} - M_{\phi n}}{\sigma_{\phi n}} \qquad (3\text{-}4)$$

where

$\sigma_{\phi b}$ = standard deviation or measure of sorting for borrow material
$\sigma_{\phi n}$ = standard deviation or measure of sorting for native material
$M_{\phi b}$ = mean sediment diameter for borrow material
$M_{\phi n}$ = mean sediment diameter for native material

Values obtained by using the relationships in Equations 3-3 and 3-4 are then plotted on the graph presented in Figure 3-7. The value of R_A can be obtained by interpolating

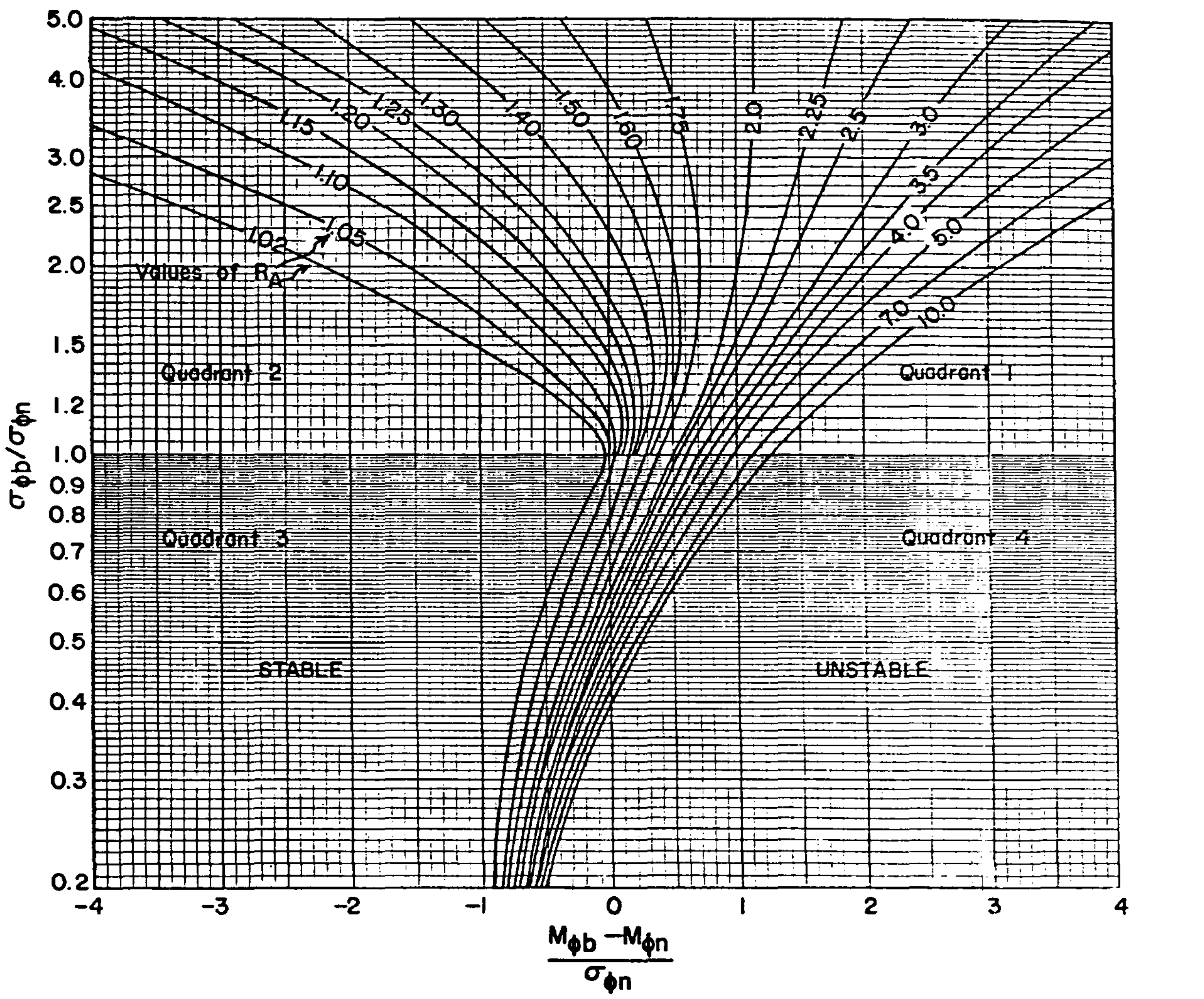

Figure 3-7. Isolines of the adjusted overfill ratio (R_A) for values of ϕ mean differences and ϕ sorting ratio (*Shore Protection Manual* 1984)

between the values represented by the isolines. For example, if the native and borrow composite grain size characteristics were:

$\sigma_{\phi b} = 0.87$
$\sigma_{\phi n} = 0.53$
$M_{\phi n} = 1.94$
$M_{\phi b} = 2.54$

the values from the relationships using Equations 3-3 and 3-4 would be

$0.87 / 0.53 = 1.6$ and $(2.54 - 1.94) / 0.53 = 1.1$

indicating that approximately 2.4 units of borrow material would be required to create 1.0 unit of stable native beach-like material. Software applications automating this process are available in the Littoral Processes module of ACES and would provide greater accuracy in determining R_A, as graphical methods have some degree of human error.

(2) Renourishment factor. Another approach developed by James (1975) relates to the long-term maintenance of a project. The renourishment factor (R_J) provides a technique to predict how often renourishment will be needed using the selected borrow material. R_J makes the same assumptions and requires the same numerical inputs as the overfill ratio and is defined as:

$$R_J = \exp\left[\Delta\left(\frac{M_{\Phi b} - M_{\Phi n}}{\sigma_{\phi n}}\right) - \frac{\Delta^2}{2}\left(\frac{\sigma^2_{\phi b}}{\sigma^2_{\phi n}} - 1\right)\right] \quad (3\text{-}5)$$

where Δ = winnowing function (recommended value is 1.0). The Δ parameter is dimensionless and represents the scaled difference between the ϕ mean non-eroding and actively eroding native beach sediments (*Shore Protection Manual* 1984). James (1975) recommends $\Delta = 1.0$ for the common situation where the textual properties of non-eroding native sediments are not known. Using the same values for the overfill ratio example presented above, the R_J value would be:

$$\begin{aligned} R_J &= \exp\,[(0.60 / 0.53) - 0.50\,\{(0.76/0.28) - 1\}] \\ &= \exp\,\{(1.13) - 0.50(1.7)\} \\ &= \exp\,(0.28) \\ &= 1.32 \end{aligned}$$

An R_J value of 1.3 would indicate that periodic renourishment using the same borrow material must be provided 1.3 times as often as using original native-like sediments in order to maintain project dimensions. R_J can also be determined graphically by using the same relationships in Equations 3-3 and 3-4 for the mean difference and sorting ratios. Plotting the same values used in the above example and interpolating between the isolines using the graph in Figure 3-8, an R_J value of 1.3 is determined, closely matching that from Equation 3-5. This parameter should be reevaluated with each renourishment for the life of the project. As with R_A, software applications automating this process are available in the Littoral Processes module of ACES. It should be noted that both the overfill ratio and renourishment factor models are based on grain size statistical parameters only and engineering judgement and experience should accompany design applications.

3-4. Comparative Evaluation of Fill Sources

In many, if not most, cases, more than one potential borrow site will be identified during the general field exploration and further investigated by a detailed site survey. A comparative evaluation of these sites is then made to select the primary borrow source for the project. This evaluation requires consideration of a number of items that in general relate to suitability of material and costs of excavation, transport, and placement. These include sediment characteristics, fill factors, renourishment factors, distance from project area, and accessibility, as discussed in previous paragraphs. The total life cycle cost of the project using each potential source should be estimated and compared in order to select the most desirable fill source.

a. Feasible means of production. In comparing potential borrow sites, it is necessary to consider the types of equipment and methods that are suitable for excavating the fill material under the environmental conditions existing at that location.

(1) In terrestrial sources, use of most types of mechanical earth excavating equipment is feasible, provided they can gain access to the site. Equipment and methods selection can be based primarily on economic and environmental factors.

(2) In submerged borrow sources, environmental conditions are more likely to impose restrictions on feasible means of production. One important factor is minimum water depth. The dredging plant used must be capable of operating in the water depths at the site without danger of grounding. In addition, it must be capable of dredging material at a depth equal to the water depth plus the anticipated pit depth.

(3) Another factor of importance is wave conditions. The dredging plants used for offshore borrow sources require ability to safely operate in open sea conditions. In more protected places such as back-barrier sources, less seaworthy plants can be used.

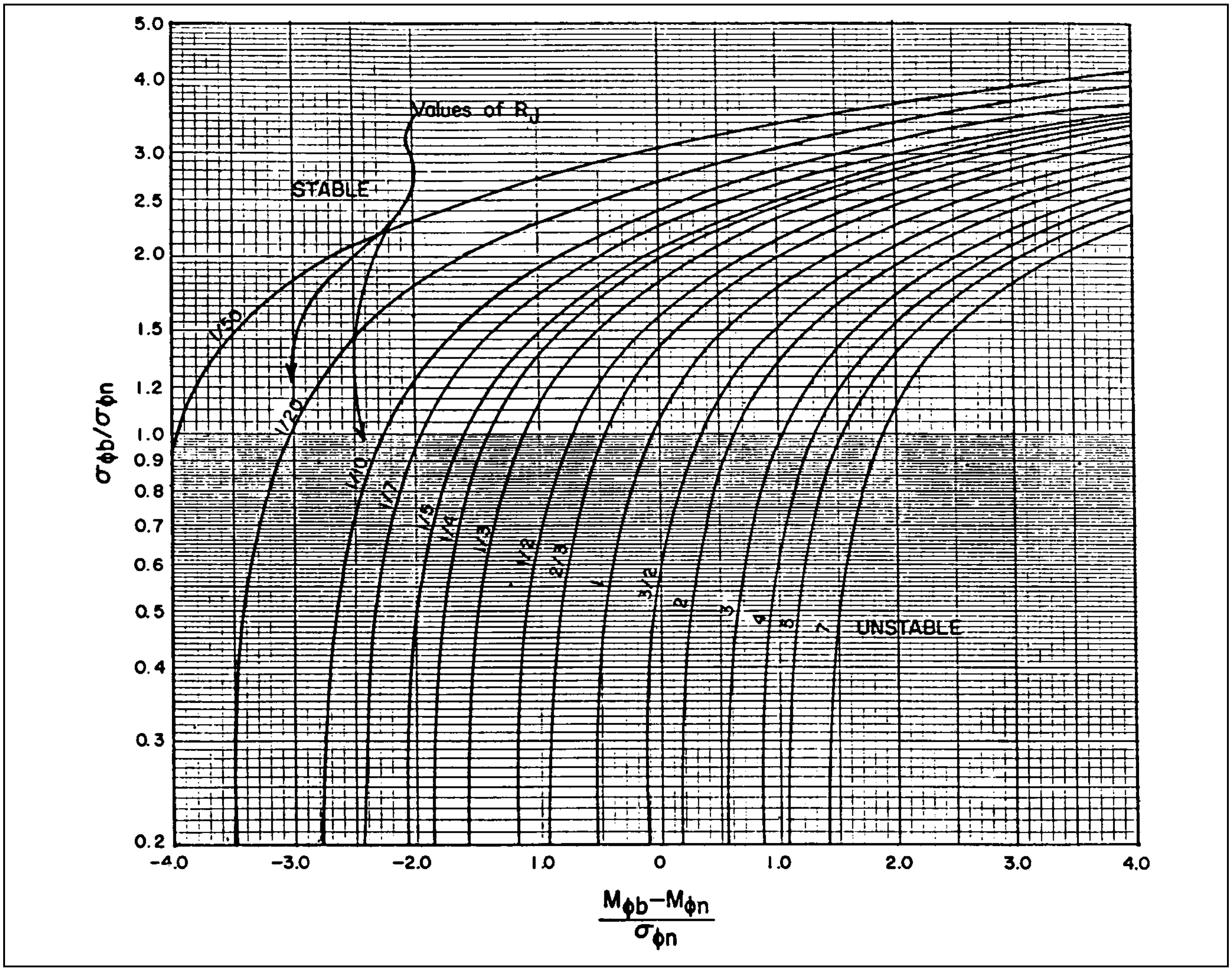

Figure 3-8. Isolines of the renourishment factor (R_J) for values of ϕ mean differences and ϕ sorting ratio (*Shore Protection Manual* 1984)

b. Environmental factors. Both biological and physical aspects of the borrow area must be considered in comparative evaluation of borrow sites. In general, environmental effects of borrow operations can be made acceptable by careful site selection, and choice of equipment, technique, and scheduling of operations. Restoration of flora and fauna often takes place in a relatively short time after operations (Stauble and Nelson 1984). Alterations in physical features may, in some circumstances, be restored by natural processes.

(1) One effect of borrow operations is direct mortality of organisms due to the operation itself, and destruction or modification of the natural habitat characteristics. Direct mortality of motile fauna such as fish is usually not great because they move to other areas during the disturbances of the borrow operation. Sessile flora and fauna cannot vacate the area; mortality of these organisms is therefore higher. However, they usually are replaced by the reproduction of survivors or stocks in unaffected peripheral areas (Stauble et al. 1982).

(2) Another serious consideration is the destruction or modification of the habitat conditions needed for survival of native species. A common alteration is the exposure of a substrate that differs from the natural substrate as a result of excavating overlying material. Many marine benthic and some pelagic organisms are adapted to specific substrate conditions. Even though larvae of the native species reach the affected area, they may not survive.

(3) In comparing borrow sites, it is necessary to consider whether or not natural substrate conditions will be modified by the planned operation. This depends on the thickness of the surficial layer and the depth of excavation needed to produce sufficient fill material. In many instances where the layer of suitable fill material is thin, an increase in the areal extent of the borrow area will allow excavation of sufficient material without altering substrate conditions. While this alternative increases direct mortality, it will preserve favorable conditions for repopulation of native organisms.

(4) In subaqueous areas, detrimental effects on native organisms, both within and peripheral to the borrow site, may occur due to the generation of suspended silt and clay size material in the water column as a result of the dredging operation. Deposits containing more than a small amount of silt and clay are thus less desirable sources of fill from an environmental standpoint. In addition, the fine fraction will be unstable in the beach environment.

(5) All borrow operations alter the local relief. In terrestrial sites, the effects of modification are usually confined to the immediate borrow area. In subaqueous deposits, the effects can be more widespread due to alteration of wave energy and refraction patterns consequent to modification of borrow relief features. To evaluate the possible adverse effects on nearby shore areas, studies for each site should be made of the alterations in wave characteristics resulting from expected changes in bottom relief features, using the procedures and tools described in Section 2-4. In some cases, the original relief can be restored by natural processes. This is more likely to occur in active features such as inlet shoals than in features that are relict, or become active only during intense storm events.